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THE ROLE OF CONVECTION IN GLASS-MELTING FURNACES

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The mechanism of formation and the dynamics of glass melt flows in glass-melting tank furnaces are considered. The results of some studies on this subject are analyzed.

The word "convection" originates from the Latin "convectio" (transfer, delivery), i.e., transport of macroscopic medium particles resulting in transfer of mass flows, heat flows, etc. Convection is distinguished as natural (free) when caused by inhomogeneity of the medium (temperatures and density gradients) and forced convection caused by an external mechanical impact on the medium (such as pumps, mixers, bubbling, etc.).

In a furnace with flame heating, a certain temperature inhomogeneity always exists in the glass melt along the length and across the width of the furnace, which is due to unequal quantities of fuel supplied to the melting, silicate- and glass-formation, refining, and cooling zones. Moreover, the temperature along the flame itself is nonuniform as well. The inhomogeneity of the temperature across the furnace width is mainly caused by heat losses via the lateral walls and a nonuniform temperature distribution in the flame. Another reason for the heterogeneity of temperature distribution in the glass melt is the batch floating on the melt surface and impeding the penetration of radiant energy directly into the glass melt.

Any inhomogeneity of temperature in a fluid medium generates natural convection. The higher the temperature gradient, the higher the convection velocity, other terms being equal. Apart from the temperature gradient, which is the driving force of convection, the velocity to a great extent depends on the physical parameters of the liquid, i.e., its viscosity, the surface tension on the interface with the gaseous and solid media, and the configuration of the channel in which the liquid flows.

The direction of the glass melt flow is determined by the position of the highest temperatures zone called "the quellpunkt," from which the glass melt moves horizontally through the upper layer toward the colder part. In sheet-glass furnaces one distinguishes two longitudinal convection cycles: the charging cycle directed beneath the batch toward the charging site, and the cooling, or working, cycle directed toward the working zone.

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In container glass furnaces, which have shorter tanks separated from the working zone by the furnace neck, only one convection cycle is formed, although some researchers have observed a reverse flow even in the neck of the furnace. Furthermore, there are cross-lateral convection cycles directed from the longitudinal axis toward the lateral walls of the tank. The convection flows are overlapped by the working glass-melt flow depending on the furnace output, which is directed only toward the working zone.

The intensity of convection is evaluated using the notion of the "flow coefficient" or the Novaki number, which is equal to the ratio of the quantity of the glass melt moving in a particular direction to the total quantity of the glass melt produced.

There are different opinions on the positive and negative role of convection in glass melting. Therefore, one should understand its nature well and appropriately use the specific features of convection.

The convection of the glass melt plays an important role in flame tank furnaces in glass melting, as it transfers a significant (up to 40%) part of the heat generated by fuel combustion under the heaps of the melting batch and removes the products of melting from this zone, and also provides for optimum working conditions. Furthermore, convection is an important homogenizing factor. The reverse (bottom) flow in the cooling cycle acts as a thermostat for the working flow by decreasing its temperature gradient across its height. However, convection in the cooling zone of the furnace produces excessive heat losses and, consequently, excessive fuel consumption.

The contribution of the glass melt velocity to heat losses via the furnace brickwork is insignificant, since this velocity is low. Heat losses in the melting and working tanks depend on the glass melt temperature directly near the furnace walls and on the surface area of the brickwork. The excessive heat loss is due to the fact that a certain part of the glass melt, which is additional to the working flow in the cooling zone, cools to the formation temperature and then returns to the melting tank and is again heated up to the maximum furnace

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temperature. Therefore, the lower the volume of the circulating glass melt, the lower is the power consumption. The above circumstance has motivated constant attempts to decrease the quantity of the glass melt directed toward the working zone. A perfect example is a direct-flow furnace in which a reverse flow is absent.

Various obstacles have been designed to restrict the working flow, such as boats, screens, pinches, or necks, and the depth of the tank has been decreased as well. However, all these measures have only lowered the intensity of the cooling convection cycle. A reverse glass melt flow has been discovered even in direct-flow furnaces. The refractory boats and screens soon become worn and by the end of the furnace campaign are ineffective. The water-cooled screens made of stainless-steel pipes in certain occasions disturb the stability of the technological regime, when pressure fluctuations in the pipeline system cause changes in the size of the lining cool glass layer around the screen, which leads to the formation of cords. A pinch, i.e., a narrowing of the furnace tank, is widely used in furnaces for sheet glass. Container glass furnaces usually have necks. There is a recent trend to design container-glass furnaces without a working tank. The feeder channels with a direct flow of glass melt stem directly from the vertical channel behind the neck. This is certainly a progressive solution, since heat losses are reduced, although in the cases of protracted pauses in the work of glass-forming machines the glass melt should be discharged to avoid its freezing in the feeder channel.

Approximated calculations of the convection intensity in the melting and cooling zones depending on the geometrical sizes and temperature conditions of the furnace and the properties (mainly viscosity) of the glass melt were performed on the basis of the formulas proposed by A. A. Sokolov [1]. It was shown in [2] that the maximum velocity of the upper glass-melt flow both in the charging cycle and in the working (cooling) cycle in the tanks of sheet-glass furnaces depends not so much on the difference between the glass melt temperatures at the beginning and at the end of the cycle as on the general average temperature, especially the temperature in the bottom layers where the flow melt viscosity is maximum. A decrease in the viscosity of the bottom glass melt layer significantly intensifies the convection and raises the melting rate (the furnace output) and the degree of homogenization of the glass melt. This can be achieved by heat-insulating the tank bottom or by additional electric heating beneath the batch-melting zone where normally the temperature of the bottom layers of the melt is minimum. Convection in the charging cycle can be intensified as well by installing additional bottom electrodes near the quellpunkt. It is advisable to supply additional energy to both zones, i.e., near the quellpunkt and in the batch-charging zone. The State Institute of Glass (GIS) based on model research has issued recommendations on the optimum power ratios for such electric-heating groups (USSR Inventor's Certif. No. 791659), which have been implemented on several large float-glass lines.

However, along with the positive role of convection most actively used in the charging cycle (heat transfer and homogenization of melt), one should note as well its negative role. First, as the glass melt velocity increases, the refractories wear more intensely, other conditions being equal. There are as yet no numerical data on the wear of the wall beams of the tanks with increasing convection. However, it can be noted that in some parts with obviously high glass melt velocities (electrode and bubble beams, necks, screens) more intense wear of refractories has always been observed.

Intensifying the convection in the working (cooling) zone of the furnace increases heat losses. At the same time it should be noted that arbitrary restriction of the convection without a thorough calculation can lead to higher energy consumption [2]. This is due to the fact that a decrease in the quantity of the glass melt arriving at the channel not only decreases the channel heat losses, but to a larger extent lowers the working glass melt temperature. An excessive temperature decrease disturbs the formation regime, which requires a higher temperature in the melting zone and, consequently, leads to higher energy consumption.

Moreover, the instability of convection when the glass melt velocity changes with time has a negative effect on the product equality. This is due to the fact that with an increasing velocity the working flow may entrain the stagnant glass melt layers whose properties differ slightly from the rest of the flow. Hypothetically it is undesirable to have turbulent flows immediately in front of the glass-forming machines. Such turbulent flows may be caused by swirling nozzles, mixers, or electric heating. There is a positive practice of using these intensifying devices in the quellpunkt zone and in the charging zone, whereas the use of mixers directly in front of the vertical-drawing machines has not produced good results [3].

One should note another type of currents, namely, the lateral glass-melt flows. They arise due to the cooling of the melt surface contacting the lateral tank beams. Having become cooled near the wall, the glass melt sinks, and its place is taken by the hotter melt. Thus the cross-lateral flows originate in the upper melt layers and move from the longitudinal axis of the furnace toward the right and the left side of the tank; next, upon sinking down to the cool bottom layers, the flow assumes a horizontal position and starts moving towards the longitudinal axis of the furnace. This partly accounts for the erosion of the tank beams at the level of the melt surface and lower.

Thus, the glass melt flow in a furnace with flame heating is clearly longitudinal with superimposed lateral flows directed from the furnace axis toward its lateral walls.

The situation in purely electric furnaces is more complicated. The electrodes inside the glass melt are the sources of upward flows. Depending on the electrode layout, several convection contours cam be formed, which are overlapped by the working flow of the glass melt moving from the batch-melting zone toward the neck. The convection velocities in electric furnaces are several times higher than in flame

furnaces, since the glass here has a homogeneous chemical composition and temperature. However, an accurate scheme of glass melt motion can be determined only using models (physical or mathematical). The temperature and velocity distributions for a furnace tank obtained on models give a better understanding of the specific technological regime of glass melting and, if necessary, makes it possible to modify the configuration of the tank brickwork and the electrode layout in order to avoid excessive energy consumption, formation of stagnant zones, and other undesirable phenomena in the furnace performance.

The schemes of the origin and dynamics of glass melt flows in glass-melting tanks considered above make it possible to promptly identify the causes of numerous types of defects and make justifiable decisions for their elimination.

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